Fuzzy Positive Implicative and Fuzzy Associative WI-Ideals of Lattice Wajsberg Algebras

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Abstract: ***We introduce the definitions of fuzzy positive implicative WI-ideal and fuzzy associative WI-ideal of lattice Wajsberg algebra. Further, we prove every fuzzy positive implicative WI-ideal of lattice Wajsberg algebra is a fuzzy WI-ideal. Also, we discuss the relationship between fuzzy positive implicative WI-ideal and level subsets. Moreover, we give the relationship of fuzzy associative WI-ideal with fuzzy WI-ideal in lattice Wajsberg algebra. Finally, we study some characterizations of fuzzy associative WI-ideal.***

Keywords: Wajsberg algebra; Lattice Wajsberg algebra; WI-ideal; Implicative WI-ideal; Positive implicative WI-ideal; Associative WI-ideal; Fuzzy positive implicative WI-ideal; Fuzzy associative WI-ideal.
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I. INTRODUCTION

The term fuzzy logic was introduced by Zadeh[9] in 1965. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. The concept of Wajsberg algebra was first proposed by MordchajWajsberg[8]in 1935, and analyzed by Font, Rodriguez, and Torrens[1] in 1984. They [2] also introduced a lattice structure of Wajsberg algebra. The authors [2] introduced the notion of *WI*-ideal of lattice Wajsberg algebra and discussed some related properties. Further, the authors [3], [4], [5], [6], "to be published"[7]introduced the notions of fuzzy *WI*-ideal, normal fuzzy *WI*-ideal, implicative *WI*-ideal, fuzzy implicative *WI*-ideal, an anti fuzzy *WI*-ideal ,positive implicative *WI*-ideal, associative *WI*-ideal of lattice Wajsberg algebras and also investigated their properties with suitable illustrations.

In this paper, we introduce the definitions of fuzzy positive implicative *WI*-ideal and fuzzy associative *WI*-ideal of lattice Wajsberg algebra. Also, we discuss the relationship between fuzzy positive implicative *WI*-ideal and fuzzy *WI*-ideal. Further, we prove that every fuzzy associative *WI*-ideal of lattice Wajsberg algebra with respect to 0 is a fuzzy *WI*-ideal. Finally, we give some of the characterizations of fuzzy associative *WI*-ideal.

II. PRELIMINARIES

We recollect basic definitions and their properties which are useful to develop our main results.

Definition 2.1[1]. Let $(A, \rightarrow, *, 1)$ be an algebra with binary operation '$\rightarrow$'and a quasi complement '*' is said to be Wajsberg algebra if it satisfies the following,

(i) $1 \rightarrow x = x$;

(ii) $(x \rightarrow y) \rightarrow y = (y \rightarrow x) \rightarrow x$;

(iii) $(x \rightarrow y) \rightarrow \big((y \rightarrow z) \rightarrow (x \rightarrow z)\big) = 1$;

(iv) $(x^* \rightarrow y^*) \rightarrow (y \rightarrow x) = 1$for all $x, y, z \in A$.

Proposition 2.2[1]. A Wajsberg algebra $(A, \rightarrow, *, 1)$ satisfies the following axioms for all $x, y, z \in A$,

(i) $x \rightarrow x = 1$;

(ii) If $(x \rightarrow y) = (y \rightarrow x) = 1$ then $x = y$;

(iii) If $(x \rightarrow y) = (y \rightarrow z) = 1$ then $x \rightarrow z = 1$;

(iv) $\big(x \rightarrow (y \rightarrow x)\big) = 1$;

(v) $(x \rightarrow y) \rightarrow \big((z \rightarrow x) \rightarrow (z \rightarrow y)\big) = 1$;

(vi) $x \rightarrow 1 = 1$;

(vii) $(x^*)^* = x$;

(viii)$(x^* \rightarrow y^*) = y \rightarrow x$;

(ix) $x \rightarrow (y \rightarrow z) = y \rightarrow (x \rightarrow z)$;

(x) $x \rightarrow 0 = x \rightarrow 1^* = x^*$.

Definition 2.3[1]. A Wajsberg algebra $(A, \rightarrow, *, 1)$ is said to be a lattice Wajsberg algebra if it satisfies the following axioms,

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(i) The partial ordering '$\leq$' on a lattice Wajsberg algebra A, such that $x \leq y$ if and only if $x \to y = 1$;

(ii) $x \wedge y = ((x^* \to y^*) \to y^*)^*$;

(iii) $x \vee y = ((x \to y) \to y)$ for all $x, y \in A$.

Note. From definition 2.3 an algebra (A, $\vee$, $\wedge$, *, 0, 1) is a lattice Wajsberg algebra with lower bound zero and upper bound one.

Definition 2.4[2]. A nonempty subset I of lattice Wajsberg algebra A is said to be *WI*-ideal of lattice Wajsberg algebra A. If it satisfies,

(i) $0 \in I$;

(ii) $(x \to y)^* \in I$ and $y \in I$ imply $x \in I$ for all $x, y \in A$.

Definition 2.5[7]. Let I be a non-empty subset of lattice Wajsberg algebra A. I is said to be a positive implicative *WI*-ideal of A, if it satisfies for all $x, y, z \in A$,

(i) $0 \in I$;

(ii) $x \in I$ and $((y \to (z \to y)^*)^* \to x)^* \in I$ imply $y \in I$.

Definition 2.6[7]. A non-empty subset I of A is called an associative *WI*-ideal of A with respect to x, where x is a fixed element of A, if it satisfies for all $x, y, z \in A$,

(i) $0 \in I$;

(ii) $((z \to y)^* \to x^*) \in I$ and $(y \to x)^* \in I$ imply $z \in I$ and $x \neq 1$.

Definition2.7[9]. Let A be a set. A function $\mu : A \to [0, 1]$ is said to be a fuzzy subset on A, for each $x \in A$ the value of $\mu(x)$ denotes a degree of membership of x in μ.

Definition 2.8[9]. Let μ be a fuzzy subset in a set A. Then the set $\{\mu_t = x \in A / \mu(x) \geq t\}$ for $t \in [0, 1]$ is called level subset of μ.

Definition 2.9[3]. Let A be a lattice Wajsberg algebra. A fuzzy subset μ of A is said to be a fuzzy *WI*-ideal of lattice Wajsberg algebra A if,

(i) $\mu(0) \geq \mu(x)$;

(ii) $\mu(x) \geq min\{\mu(x \to y)^*, \mu(y)\}$ for all $x, y \in A$.

Proposition 2.10[7]. Let M and N be two *WI*-ideals of lattice Wajsberg algebra A with $M \subseteq N$. If M is a positive implicative *WI*-ideal of A then so is N.

III. MAIN RESULTS

3.1. Fuzzy Positive Implicative *WI*-ideal

We introduce the concept of fuzzy positive implicative *WI*-ideal of lattice Wajsberg algebra A and study some of its properties.

Definition 3.1.1. A fuzzy subset μ of lattice Wajsberg algebra A is called a fuzzy positive implicative *WI*-ideal of A if for all $x, y, z \in A$,

(i) $\mu(0) \geq \mu(x)$;

(ii) $\mu(y) \geq min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}$.

Example 3.1.2. A set $A = \{0, i, j, k, 1\}$ with partial ordering as in the 'Fig.1'. Defining a binary operation '$\to$' and a quasi complement '$*$' on A as given in tables I and II.

Fig. 1
Lattice diagram

Table I: Complement

x	x^*
0	1
i	k
j	j
k	i
1	0

Table II: Implication

$\to$	0	i	j	k	1
0	1	1	1	1	1
i	k	1	1	1	1
j	j	k	1	1	1
k	i	j	1	1	1
1	0	i	j	k	1

Define $\wedge$ *and* $\vee$ on A as follows:

$x \wedge y = ((x^* \to y^*) \to y^*)^*$; $x \vee y = ((x \to y) \to y)$ for all $x, y \in A$.

Then, $(A, \vee, \wedge, \to, 0, 1)$ is a lattice Wajsberg algebra. A fuzzy subset μ of A is defined by,

$$\mu(x) = \begin{cases} .68 \ \ when\ x = 0 & for\ all\ x \in A \\ .21 \ \ when\ x = \{i, j, k, 1\} & for\ all\ x \in A \end{cases}$$

Then, a fuzzy subset μ is a fuzzy positive implicative *WI*-ideal of lattice Wajsberg algebra A.

Proposition 3.1.3. Every fuzzy positive implicative *WI*-ideal of lattice Wajsberg algebra A is a fuzzy *WI*-ideal of A.

Proof. Let μ be a fuzzy positive implicative *WI*-ideal of A, then from (ii) of definition 3.1.1 we have

$\mu(y) \geq \min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}$ for all $x, y, z \in A$. (3.1.1)

Taking $x = y$, $y = x$ and $z = x$ in (3.1.1)

We obtain

$$\mu(x) \geq min\{\mu\ (x \to (x \to x)^*)^* \to y)^*), \mu\ (y)\}$$

$= min\{\mu(((x \to 1)^* \to y)^*)^*, \mu(y)\}$
$= min\{\mu(((x \to 0)^* \to y)^*)^*, \mu(y)\}$
$= min\{\mu((x \to y))^*, \mu(y)\}.$

Thus, we have $\mu(x) \geq min\{\mu((x \to y))^*, \mu(y)\}$, and $\mu(0) \geq \mu(x)$[From (i) of definition 3.1.1]

Hence, μ is a fuzzy *WI*-ideal of *A*.■

Note. The converse of the above proposition may not be true.

Proposition 3.1.4. Let μ be a fuzzy implicative *WI*-ideal of lattice Wajsberg algebra *A*. μ is a fuzzy positive implicative *WI*-ideal of *A* if and only if $\mu(x) \geq \mu(((x \to (y \to x)^*)^*)$for all $x, y \in A$.

Proof. Let μ be a fuzzy positive implicative *WI*-ideal of *A*, then from (ii) of definition 3.1.1 we have

$\mu(y) \geq min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}$ for all $x, y, z \in A$. (3.1.2)

Substituting $x = 0, y = x$, and $z = y$ in (3.1.2)

We obtain $\mu(x) \geq min\{\mu(((x \to (y \to x)^*)^* \to 0)^*, \mu(0)\}$
$= \min\{\mu((x \to (y \to x)^*)), \mu(0)\}$
$= \mu((x \to (y \to x)^*)^*)$

Conversely, suppose μ is a fuzzy *WI*-ideal and it satisfies the inequality,

$\mu(x) \geq \mu((x \to (y \to x)^*)^*)$ for all $x, y, z \in A$ (3.1.3)

Put $x = y$ in (3.1.3), then, we have

$\mu(y) \geq \mu((y \to (z \to y)^*)^*)$
$\geq min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}.$

Thus, we have

$\mu(y) \geq \min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\},$

and$\mu(0) \geq \mu(x)$[From (i) of definition 3.1.1]

Hence, μ is a fuzzy positive implicative *WI*-ideal of *A*.■

Proposition 3.1.5. If μ is a fuzzy positive implicative *WI*-ideal of lattice Wajsberg algebra *A* then, $I = \{x \in A / \mu(x) = \mu(0)\}$ is a positive implicative *WI*-ideal of *A*.

Proof. Let μ be a fuzzy positive implicative *WI*-ideal of *A* and$I = \{x \in A / \mu(x) = \mu(0)\}$.

Obviously, $0 \in A$. Let $((y \to (z \to y)^*)^* \to x)^*) \in I, x \in I$ for all $x, y, z \in A$.

Then, we have $\mu(((y \to (z \to y)^*)^* \to x)^*) = \mu(0)$ and $\mu(x) = \mu(0)$ (3.1.4)

Since μ is a fuzzy positive implicative *WI*-ideal, we have$\mu(y) \geq min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}$

[From (ii) of definition 3.1.1]

$= \mu(0)$ [From 3.1.4]

and $\mu(0) \geq \mu(y)$ [From (i) of definition 3.1.1]

Then, we get $\mu(y) = \mu(0)$

Thus, $y \in I$ it follows that *I* is a positive implicative *WI*-ideal of *A*.■

Proposition 3.1.6. Let μ be a fuzzy subset of lattice Wajsberg algebra *A*. μ is a fuzzy positive implicative *WI*-ideal of *A* if and only if $\mu(\alpha, \beta)$ is a positive implicative *WI*-ideal of *A*, when $\mu(\alpha, \beta) \neq \emptyset; \alpha, \beta \in [0, 1]$.

Proof. Let μ be a fuzzy positive implicative *WI*-ideal of *A* and $\alpha, \beta \in [0,1]$ such that $\mu(\alpha, \beta) \neq \emptyset$. Clearly $0 \in \mu(\alpha, \beta)$.

Let $((y \to (z \to y)^*)^* \to x)^* \in \mu(\alpha, \beta), x \in \mu(\alpha, \beta)$ for all $x, y, z \in A$.Then, we have

$\mu(((y \to (z \to y)^*)^* \to x)^* \geq [\alpha, \beta], \mu(x) \geq [\alpha, \beta].$

It follows that,

$\mu(y) \geq min\{\mu(((y \to (z \to y)^*)^* \to x)), \mu(x)\} \geq [\alpha, \beta].$

Thus, $y \in \mu[\alpha, \beta]$. Hence, we have $\mu[\alpha, \beta]$ is a positive implicative *WI*-ideal of *A*.

Conversely, suppose that $\mu(\alpha, \beta) \neq \emptyset$ is a positive implicative *WI*-ideal of *A*, where $\alpha, \beta \in [0, 1]$. For any $x \in A$, and $x \in \mu_\mu(x)$, it follows that $\mu_\mu(x)$ is a positive implicative*WI*-ideal of *A*.

Thus, $0 \in \mu_\mu(x)$. That is $\mu(0) \geq \mu(x)$ for all $x, y, z \in A$.

Let $[\alpha, \beta] = \min\{\mu(((y \to (z \to y)^*)^* \to x)^*)^*, \mu(x)\}$, it follows that $\mu(\alpha, \beta)$ is a positive implicative *WI*-ideal and $((y \to (z \to y)^*)^* \to x)^*)^* \in \mu[\alpha, \beta]$, and $x \in \mu[\alpha, \beta]$.

This implies that $y \in \mu[\alpha, \beta]$. So,

$\mu(y) \geq [\alpha, \beta] = min\{\mu(((y \to (z \to y)^*)^* \to x)^*), \mu(x)\}$

Hence, we get μ is a fuzzy positive implicative *WI*-ideal of *A*. ■

Corollary 3.1.7. A fuzzy subset$\mu$of lattice Wajsberg algebra *A* is a fuzzy positive implicative *WI*-ideal of *A* if and only if μ_α is a positive implicative *WI*-ideal of *A*, when$\mu_\alpha \neq \emptyset$, $\alpha \in [0,1]$.

Proposition 3.1.8. Let *M* and *N* be implicative *WI*-ideals of lattice Wajsberg algebra *A*, such that $M \subseteq N$. If μ is a fuzzy

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positive implicative *WI*-ideal of M. Then so N.

Proof. Let M and N be implicative *WI*-ideals of lattice Wajsberg algebra A. Let μ be a fuzzy positive implicative *WI*-ideal of M. Since $M \subseteq N$, $\mu_M(x) \leq \mu_N(x)$ for all $x \in A$. Then, clearly $M_\alpha \leq N_\alpha$ for every $\alpha \in [0,1]$. If μ_M is a fuzzy positive implicative *WI*-ideal of A. Hence, we get M_α is a positive implicative *WI*-ideal of A. [From corollary 3.1.7]

Then, N_α is a positive implicative *WI*-ideal of A.

[From Proposition 2.10]

Thus, μ_N is fuzzy positive implicative *WI*-ideal. Hence, μ is a fuzzy positive implicative *WI*-ideal of N. ■

3.2. Fuzzy Associative *WI*-ideal

We introduce an idea of fuzzy associative *WI*-ideal of lattice Wajsberg algebra $A$and examine its properties,

Definition 3.2.1.A fuzzy subset $\mu$of lattice Wajsberg algebra A is said to be a fuzzy associative *WI*-ideal of A with respect to x, where x is a fixed element of A, if it satisfies,

(i) $\mu(0) \geq \mu(x)$;

(ii) $\mu(z) \geq min\{\mu((z \to y)^* \to x)^*, \mu((y \to x)^*)\}$

for all $x, y, z \in A$.

A fuzzy associative *WI*-ideal with respect to all $x \neq 1$ is called a fuzzy associative *WI*-ideal. Fuzzy associative *WI*-ideal with respect to 1 is constant.

Example 3.2.2.A set $A = \{0, d, e, 1\}$ with partial ordering as in "Fig. 2". Define '$*$' and '$\to$' on A as given in tables III and IV.

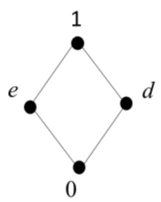

Table III: Complement

x	x^*
0	1
d	e
e	d
1	0

Table IV: Implication

$\to$	0	d	e	1
0	1	1	1	1
d	e	1	1	1
e	d	e	1	1
1	0	d	e	1

Fig.2.Lattice diagram

Here, A is a lattice Wajsberg algebra. A fuzzy subset μ of $A$is defined by,

$$\mu(x) = \begin{cases} .54 \ when \ x = 0 & for \ all \ x \in A \\ .33 \ when \ x = \{d, e, 1\} & for \ all \ x \in A \end{cases}$$

Then, μ is a fuzzy associative *WI*-ideal of A.

Proposition 3.2.3. If μ is a fuzzy associative *WI*-ideal of A with respect to x then $\mu(x) = \mu(0)$.

Proof. Let μ be a fuzzy associative *WI*-ideal of A with respect to x if $x = (0, 1)$.Then it is trivial, we assume that x is neither 0 nor 1. Then,

$$\mu(x) \geq min\{\mu(((x \to 0)^* \to x)^*, \mu((0 \to x)^*)\}$$

[From (ii) of definition 3.2.1]

Hence, we get $\mu(x) = \mu(0)$.■

Proposition 3.2.4. Every fuzzy associative *WI*-ideal of lattice Wajsberg algebra$A$ with respect to 0 is a fuzzy *WI*-ideal of A.

Proof. If μ is a fuzzy associative *WI*-ideal of A with respect to 0.Then, we have

$\mu(x) \geq \min\{\mu((x \to y)^* \to 0), \mu((y \to 0)^*)\}$ for all $x, y \in A$ [From (ii) of definition 3.2.1]

$= min\{\mu((x \to y)^*), \mu(y)\}$

Hence, we have μ is a fuzzy *WI*-ideal of A.■

Proposition 3.2.5. Let μ be a fuzzy *WI*-ideal of lattice Wajsberg algebra A. μ is a fuzzy associative *WI*-ideal of A if and only if it satisfies, $\mu((z \to (y \to x)^*)^*) \geq \mu(((z \to$ *y∗→x∗*for all *x,y,z∈A.*

Proof. Let μ be a fuzzy *WI*-ideal of A satisfying $\mu((z \to$ *y→x∗∗≥μz→y∗→x∗* for all *x,y,z∈A*

Then we have,

$$\mu(z) \geq min\{\mu((z \to (y \to x)^*)^*), \mu((y \to x)^*)\}$$
$$= min\{\mu(((z \to y)^* \to x)^*), \mu((y \to x))^*)\}$$

So, μ is a fuzzy associative *WI*-ideal of A.

Conversely, suppose that μ be a fuzzy associative *WI*-ideal of A. Then we have, $\mu((z \to (y \to x)^*)^*) \geq min\{\mu(((z \to$ *y→x∗∗→z→ y∗∗→x∗,μ(z→y∗→x∗)*

Let us consider,

$$(((z \to (y \to x)^*)^* \to (z \to y)^*)^* \to x$$
$$= x^* \to ((z \to (y \to x)^*)^* \to (z \to y)^*)$$
$$= x^* \to \left((z \to y) \to (z \to (y \to x)^*)\right)$$
$$= (x \to y) \to \left(x^* \to \left((y \to x) \to z^*\right)\right)$$
$$= (z \to y) \to \left((y \to x) \to (x^* \to z^*)\right)$$
$$= (z \to y) \to \left((z \to y) \to (z \to y)\right)$$
$$= 1$$

It follows that

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$$\mu((z \to (y \to x)^*)^*) \geq \min\{\mu(0), \mu(((z \to y)^* \to x)^*)\}$$
$$= \mu(((z \to y)^* \to x^*)$$

Hence, we have

$\mu((z \to (y \to x)^*)^*) \geq \mu(((z \to y)^* \to x)^*)$. ■

Proposition 3.2.6. Let μ be a fuzzy *WI*-ideal of lattice Wajsberg algebra A. μ is a fuzzy associative *WI*-ideal of A if and only if it satisfies $\mu(z) \geq \mu\left(\left((z \to x) \to x\right)^*\right)$ for all $x, z \in A$.

Proof. Let μ be a fuzzy associative *WI*-ideal of A.

Then from (ii) of definition 3.2.1 we have,

$\mu(z) \geq min\{\mu(((z \to y)^* \to x)^*), \mu((y \to x)^*)\}$ for all $x, y, z \in A$. (3.2.1)

Taking $y = x$ in 3.2.1 we get,

$$\mu(z) \geq min\{\mu(((z \to x)^* \to x)^*), \mu((x \to x)^*)\}$$
$$= min\{\mu(((z \to x)^* \to x)^*), \mu(0)\}$$
$$= \mu\left(\left((z \to x) \to x\right)^*\right)$$

Conversely, if μ is a fuzzy *WI*-ideal and satisfies $\mu(z) \geq \mu\left(\left((z \to x) \to x\right)^*\right)$ for $x, z \in A$

Clearly, $\left(((z \to x)^*) \to (y \to x)^*\right)^* \to (z \to y)^*)^* = 0$

and $((z \to y)^* \to (z \to x)^*)^* \leq (x \to y)^*$

It follows that,

$$(((z \to (y \to x)^*)^* \to x)^* \to x)^* \to ((z \to y)^* \to x)^*)^* = 0$$
$$\mu((z \to (y \to x)^*)^*) \geq \mu\left(((z \to y \to x)^*) \to x)^* \to x)^*\right)$$
$$\geq min\{\mu((((z \to (y \to x)^* \to x)^*)^*,\ \mu\ ((z \to y)^* \to$$
$x**$
$$\mu(((z \to y)^* \to x)^*) = min\ \{\mu(0), \mu(((z \to y)^* \to x)^*)\}$$
$$= \mu(((z \to y)^* \to x)^*)$$

From proposition 3.2.3, we get μ is a fuzzy associative *WI*-ideal of A. ■

IV. CONCLUSION

In this paper, we have introduced the notions of fuzzy positive implicative *WI*-ideal and fuzzy associative *WI*-ideal of lattice Wajsberg algebras. Further, we have discussed the relationship between fuzzy positive implicative *WI*-ideal and fuzzy *WI*-ideal, fuzzy associative *WI*-ideal and fuzzy *WI*-ideal in lattice Wajsberg algebra. Moreover, we have given some of the characterizations of fuzzy associative *WI*-ideal.

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